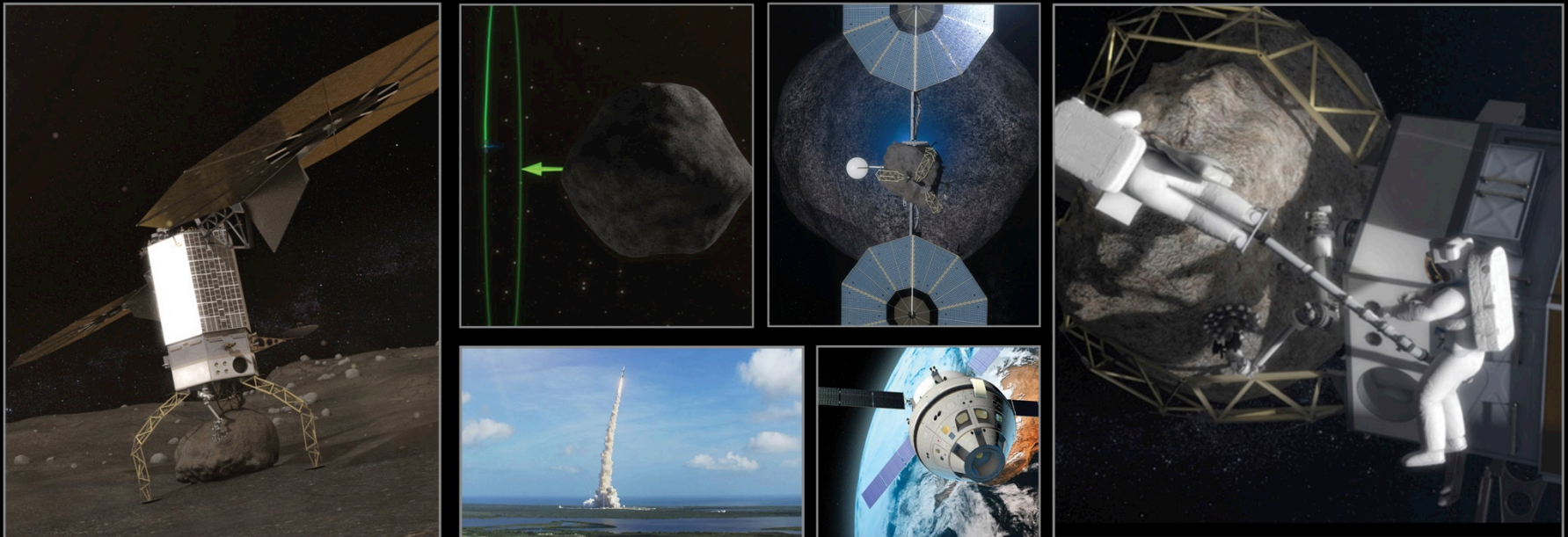


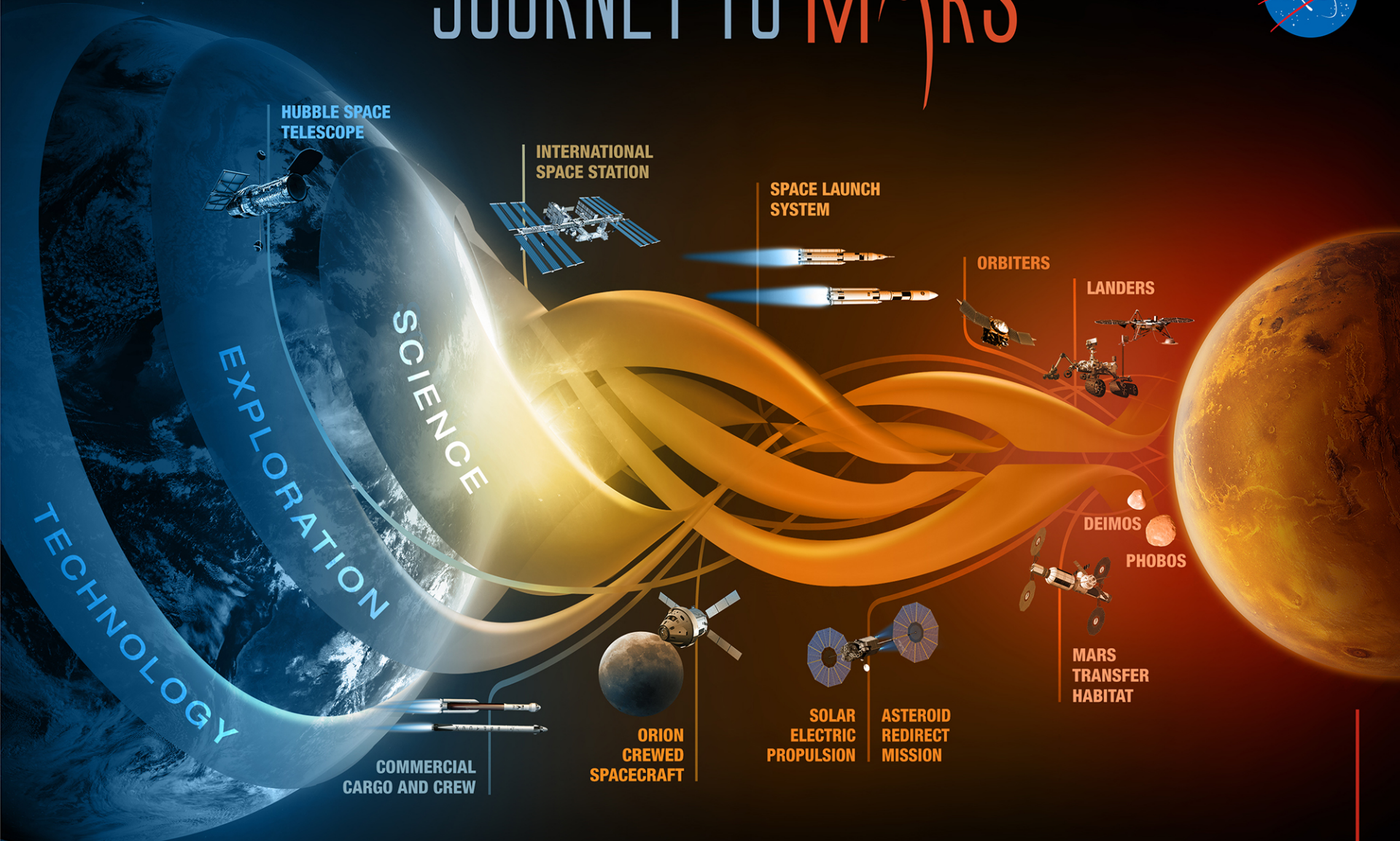
Asteroid Redirect Mission Update

Dr. Michele Gates

NAC Human Exploration and Operations Committee
July 28, 2015



JOURNEY TO MARS



MISSIONS: 6-12 MONTHS
RETURN: HOURS

EARTH RELIANT

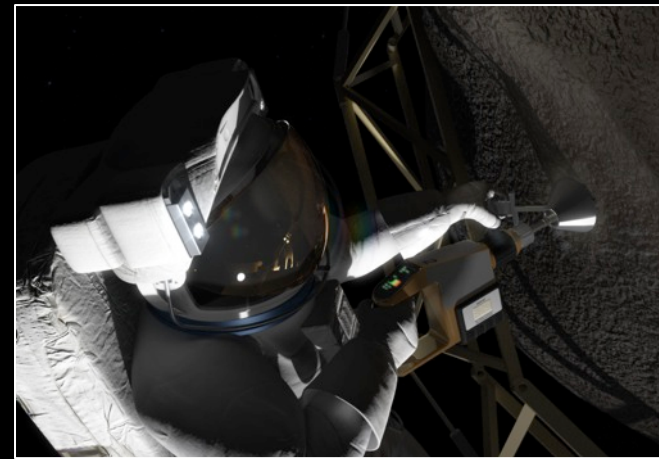
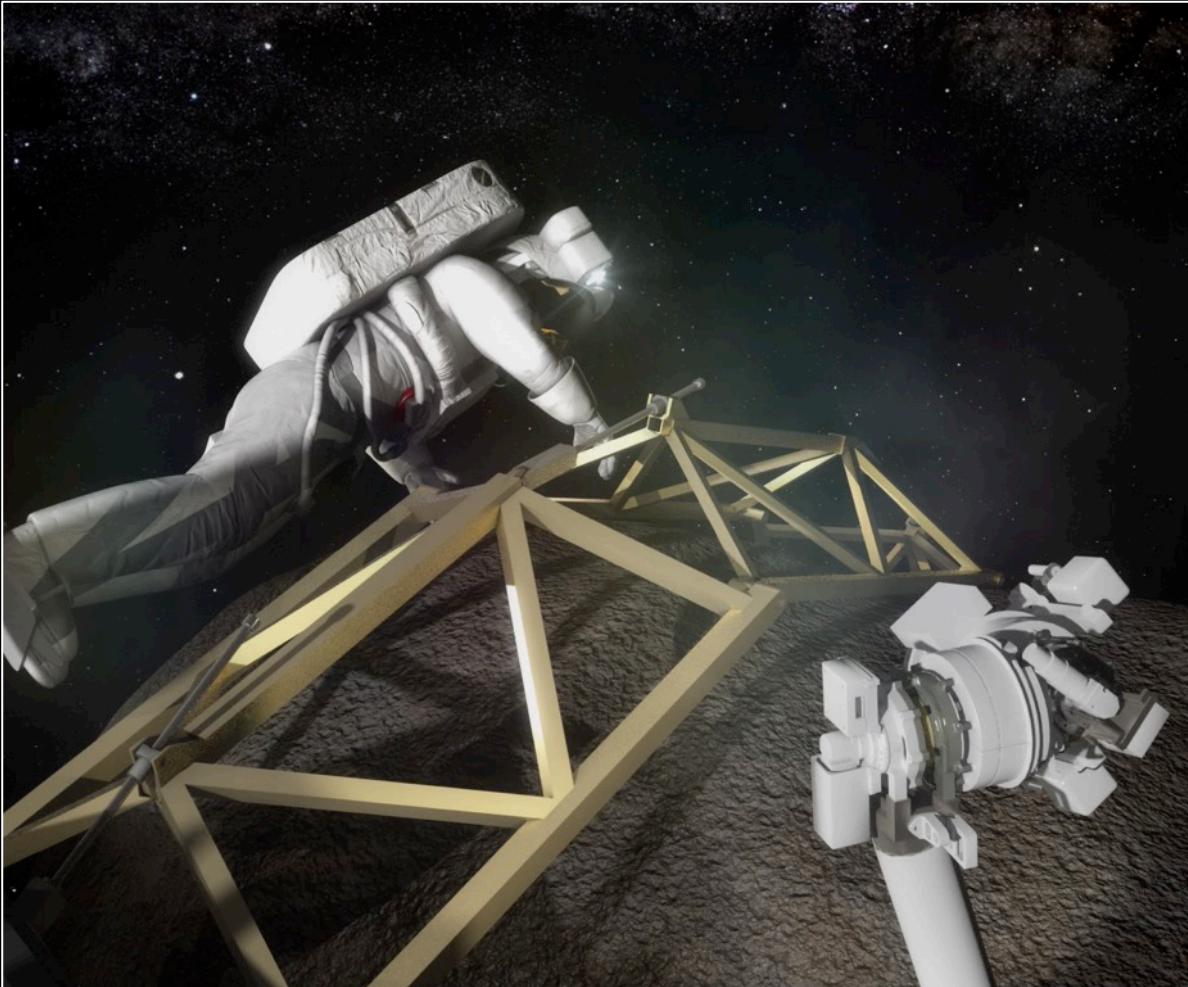
MISSIONS: 1-12 MONTHS
RETURN: DAYS

PROVING GROUND

MISSIONS: 2-3 YEARS
RETURN: MONTHS

EARTH INDEPENDENT

Crew Operations in 2025



Concept development led by Johnson Space Center

Last Update in March Included:

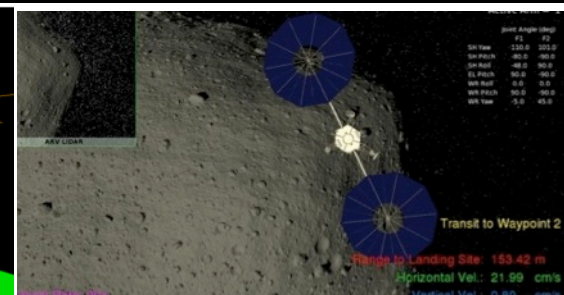
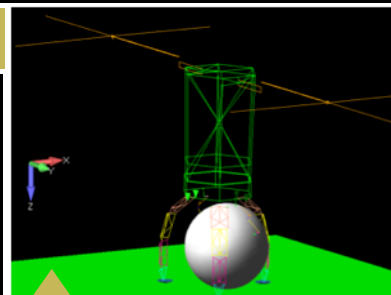
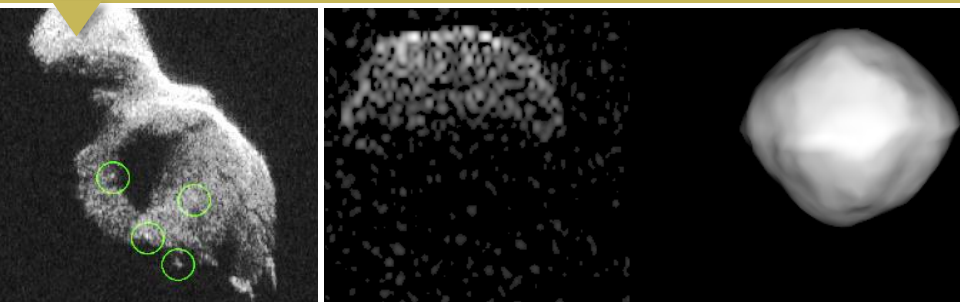


- **Updates on contributions of the mission in the exploration strategy and journey to Mars.**
- **Results of industry study and risk reduction contracts**
- **Overview of MCR for robotic mission (ARRM)**
- **Guidance for ARRM formulation**
- **Draft Level 1 requirements for robotic mission**
- **Overview of robotic mission concept**
 - Reference flight system overview
 - Solar electric propulsion system performance description
 - Capture module system concept
 - Reference concept integration and test flow
 - Development schedule

Asteroid Redirect Mission: 2015 Advancements

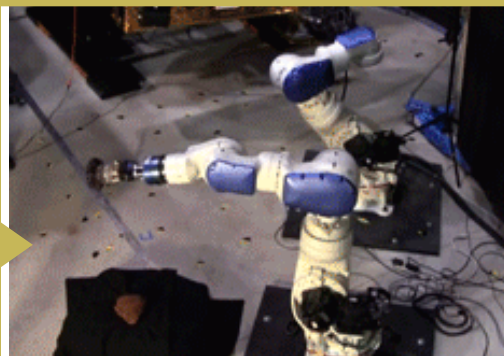


IDENTIFYING CANDIDATE ASTEROIDS



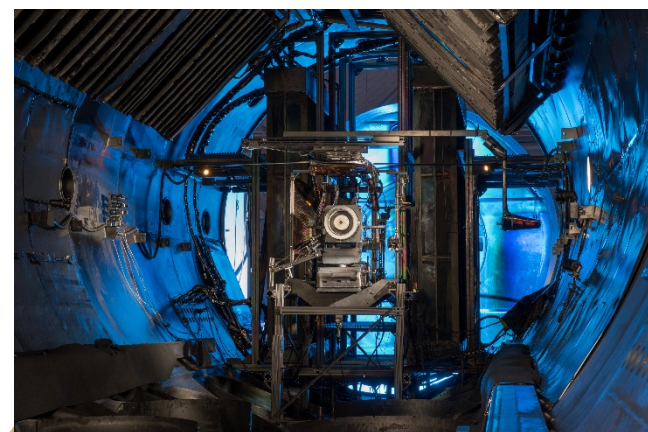
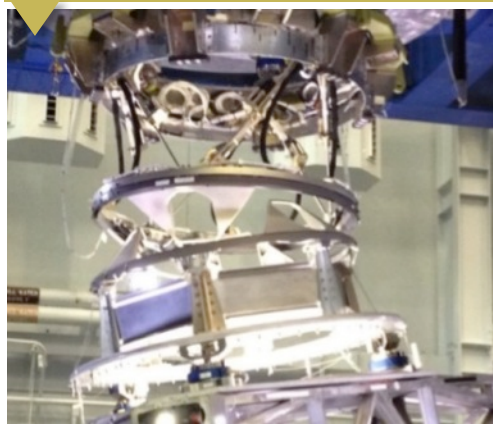
MISSION DESIGN AND SIMULATION OF CRITICAL MISSION OPERATIONS

PROTOTYPING AND TESTING CAPTURE OPTIONS



VACUUM PRESSURE INTEGRATED SUIT TESTING

INTERNATIONAL DOCKING SYSTEM



SOLAR ELECTRIC PROPULSION

Objectives of Asteroid Redirect Mission

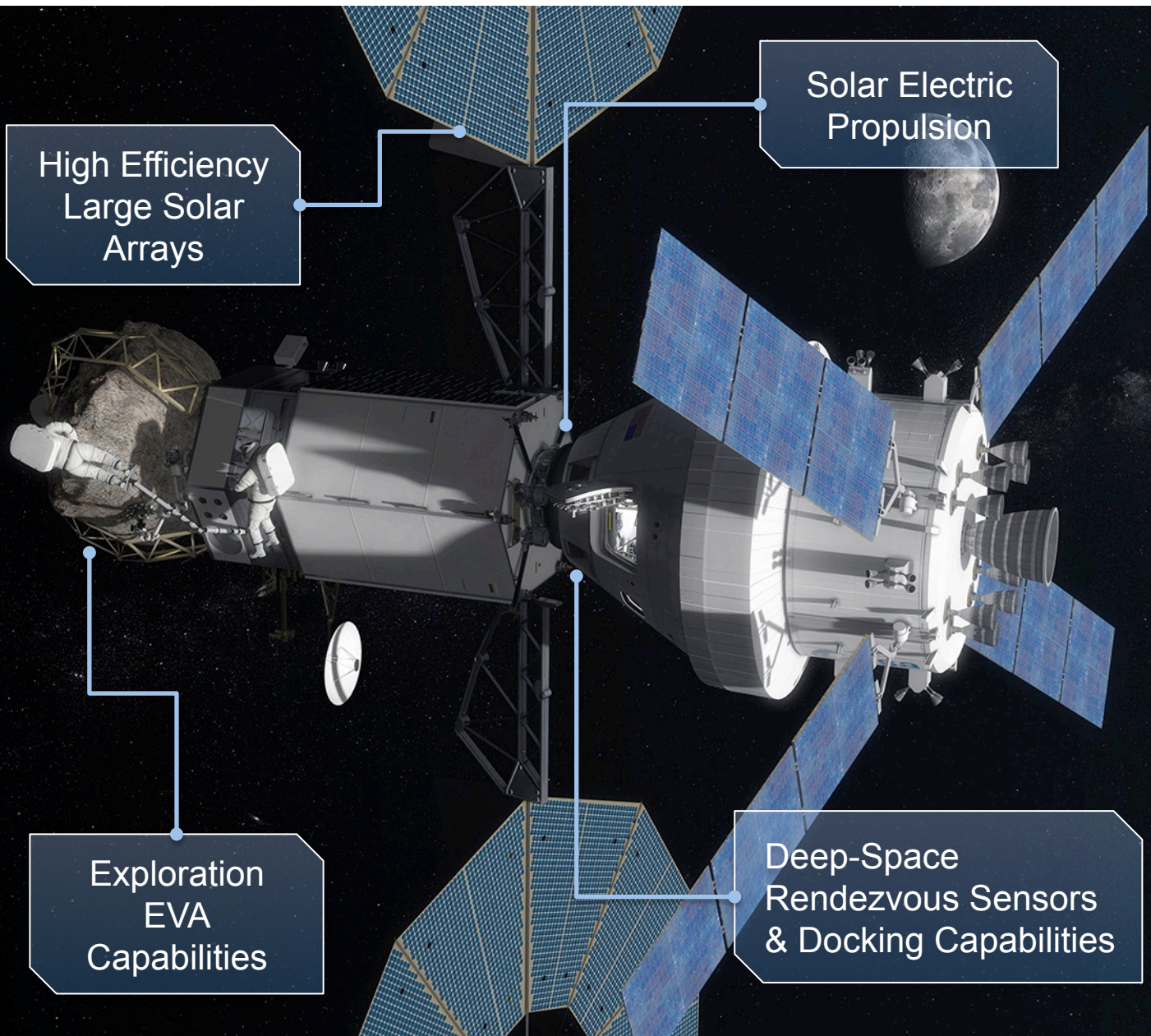


- 1. Conduct a human spaceflight mission involving in-space interaction with an asteroid boulder in the mid 2020's, providing systems and operational experience required for human exploration of Mars.**
- 2. Demonstrate an advanced solar electric propulsion system, enabling future deep-space human and robotic exploration with applicability to the nation's public and private sector space needs.**
- 3. Enhance detection, tracking and characterization of Near Earth Asteroids, enabling an overall strategy to defend our home planet.**
- 4. Demonstrate basic planetary defense techniques that will inform impact threat mitigation strategies to defend our home planet.**
- 5. Pursue a target of opportunity that benefits scientific and partnership interests, expanding our knowledge of small celestial bodies and enabling the mining of asteroid resources for commercial and exploration needs.**

ARM human space flight demonstration objectives in the Proving Ground are an important early step to longer term crew activities in deep space

- **Transporting multi-ton objects with advanced solar electric propulsion**
- **Integrated crewed/robotic vehicle operations in deep space staging orbits**
- **Advanced autonomous proximity operations and rendezvous in deep space and with non-cooperative objects**
- **Astronaut EVA for sample selection, handling, and containment**
- **Maintaining Earth return trajectories and emergency return strategies**

ARM: A Capability Demonstration Mission



IN-SPACE POWER & PROPULSION:

- High efficiency 40kW SEP extensible to Mars cargo missions
- Power enhancements feed forward to deep-space habitats and transit vehicles

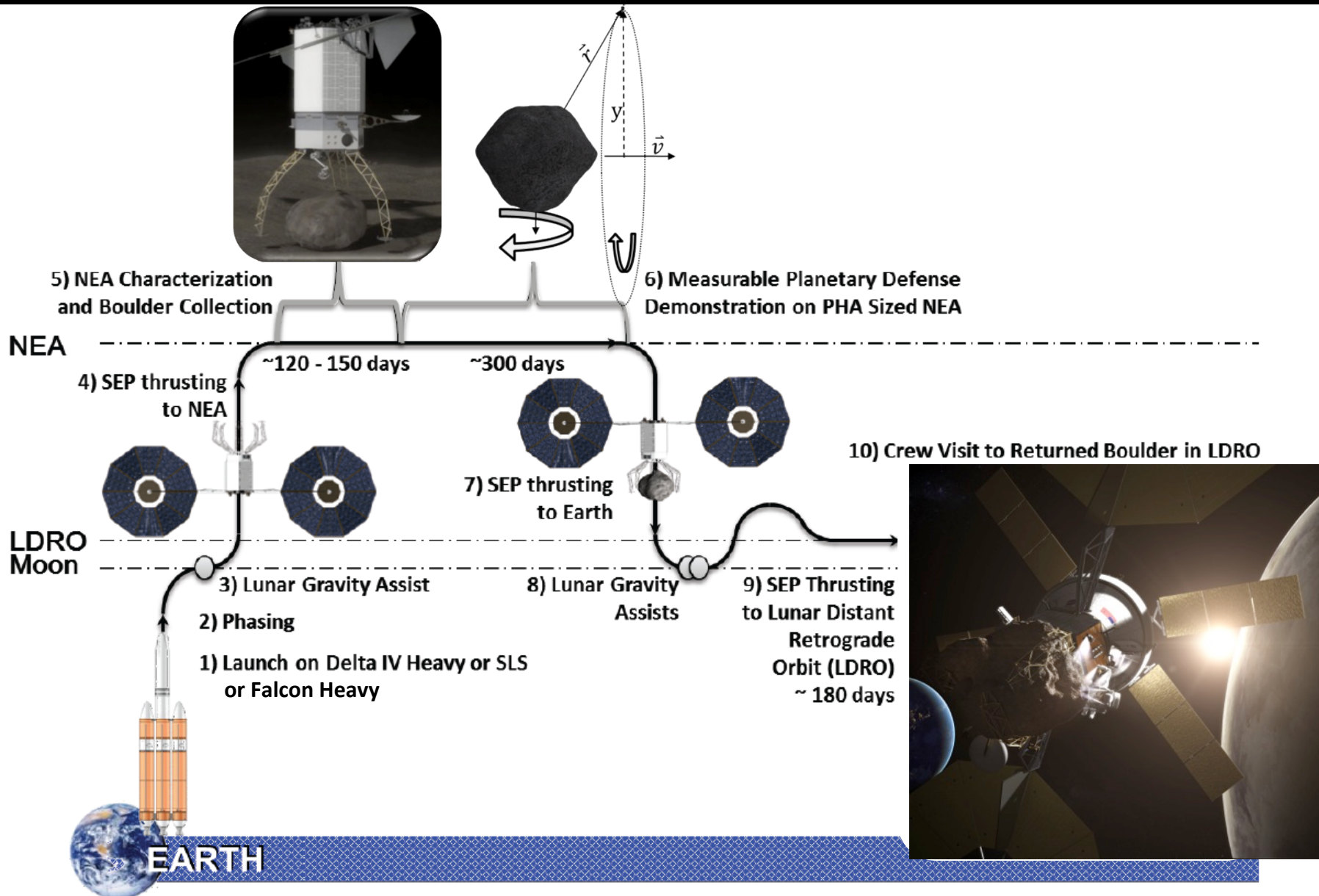
EXTRAVEHICULAR ACTIVITIES:

- Primary Life Support System design accommodates Mars
- Sample collection and containment techniques
- Follow-on missions in DRO can provide more capable exploration suit and tools

TRANSPORTATION & OPERATIONS:

- Capture and control of non-cooperative objects
- Rendezvous sensors and docking systems for deep space
- Cis-lunar operations are proving ground for deep space operations, trajectory, and navigation

ARRM Mission Concept Overview



- **Capture option B**
- **Draft Level 1 requirements**
- **Target robotic mission launch date Dec 2020**
- **Robotic mission cost cap \$1.25B not including launch vehicle and mission operations (Phase E)**
- **Internal and external dependencies**
- **Define capability demonstration implementation approach**
- **Target crewed mission launch date Dec 2025**

NASA Approval to Proceed to begin Phase A Formulation for Robotic Mission

Asteroid Redirect Robotic Mission (ARRM)

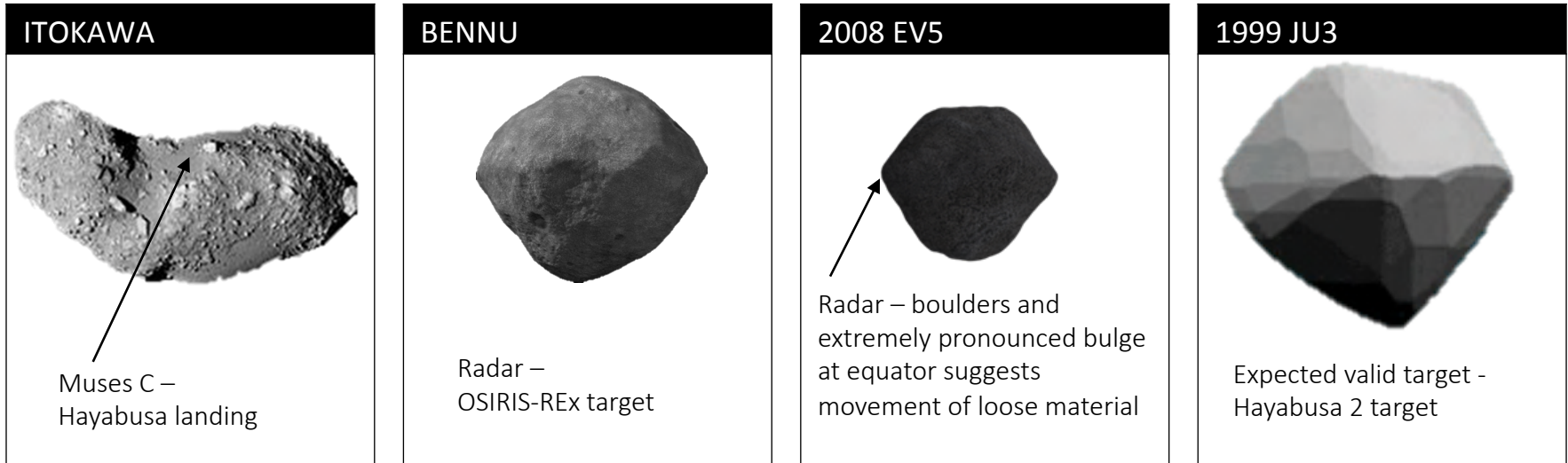
Top Level Requirements



In addition to requirements to fulfill the mission objectives:

- ARRM shall be interface compatible with EELV-class launch vehicles, Falcon Heavy, and SLS until launch vehicle selection, expected by Project System Design Review.
- ARRM shall implement the project as a capability demonstration mission including defining and applying lean implementation techniques to achieve a launch readiness by the end of 2020 with a cost capped budget of <\$1.25B (not including launch vehicle or Operations).
- ARRM shall provide resources including power and communications for future potential visiting vehicles, release of the asteroid and provide the provisions for future refueling (Xe and N₂H₄).

Current Candidate Parent Asteroids



Asteroids not to scale

Comparison of current candidate parent asteroids

	Itokawa	Bennu	2008 EV ₅	1999 JU ₃
Size	535 x 294 x 209 m	492 x 508 x 546 m	420 x 410 x 390 m	870 m diameter
V_{∞}	5.68 km/s	6.36 km/s	4.41 km/s	5.08 km/s
Aphelion	1.70 AU	1.36 AU	1.04 AU	1.42 AU
Spin Period	12.13 hr	4.297 hr	3.725 hr	7.627 hr
Type	S	B (C-grp volatile rich)	C (volatile rich)	C (volatile rich)
Precursor	Hayabusa (2005)	OSIRIS-REx (9/2016 launch, 8/2018 arrival)	None currently planned (boulders implied from 2008 radar imaging)	Hayabusa 2 (launched 12/4/2014, 7/2018 arrival)

NASA continues to look for additional targets in accessible orbits.

Reference ARRMM Target

External Engagement (1)



- **June 2013: NASA issued a Request for Information (RFI) to seek new ideas on how to implement the ARM and Agency Grand Challenge, alternative ARM concepts, and innovative approaches to broaden participation from partners and the public.**
 - Received 402 responses, invited 96 response ideas for further exploration, acted on many of them
- **Ideas Synthesis**
- **March 2014: NASA issued the Asteroid Redirect Mission Broad Agency Announcement (BAA), soliciting proposals for concept studies in areas including asteroid capture systems, rendezvous sensors, adapting commercial spacecraft for the Asteroid Redirect Mission and feasibility studies of potential future partnership opportunities for secondary payloads and the crewed mission.**
 - In June 2014, NASA announced it selected 18 of the 108 BAA proposals for six-month studies, totaling \$4.9 million in awards.

External Engagement (2)



- **Interactions and assessments, information during pre-formulation**
 - Briefings and interactions with feedback
 - SBAG Special Action Team – August 2014
 - Curation and Planning Team for Extra-Terrestrial Materials input – December 2014
- **Expert and Citizen Assessment of Science and Technology**
 - Phoenix, AZ and Boston, MA: fall and winter 2014
- **May 2015: NASA issued another RFI for Spacecraft Bus Concepts to Support the Asteroid Redirect Robotic Mission and In-Space Robotic Servicing**
 - Additional information for acquisition strategy
- **June 2015 Notice of formation of FAST**
 - Toward Investigation Team for mission

ARM External Input Status



- **Input from the early RFI, study contracts solicited through BAAs, SBAG SAT, and CAPTEM were folded into the Robotic Mission downselection, pre-Acquisition Strategy Meeting, and Mission Concept Review.**
- **Responses to the recent RFI are also input into Acquisition Strategy decisions. Acquisition Strategy Meeting is scheduled for Aug 4.**
- **NASA is organizing an ARM Investigation Team (IT), which will be preceded by the FAST (Formulation Assessment and Support Team). These teams will be comprised of scientists, technologists, and other qualified and interested individuals to help plan the implementation and execution of ARM.**

Small Bodies Assessment Group (SBAG)

Semi-Annual Meeting June 2015



SBAG appreciates NASA's efforts to engage and communicate with the planetary defense and small bodies science communities about the Asteroid Redirect Mission (ARM) and the extent to which modifications in mission design have been responsive to concerns from those groups.

In particular, the reference target asteroid 2008 EV₅ offers well-documented opportunities, having been previously the sample return target for ESA's MacroPolo-R candidate mission. SBAG encourages continued engagement between mission planners and the small bodies community as the mission moves forward and supports the plans for the competed Formulation Assessment and Support Team (FAST) and the succeeding Investigation Team (IT). However, it is important to note that for science-driven missions, SBAG continues to support the priorities identified in the Decadal Survey to guide use of Planetary Science Division (PSD) resources and funds.

Draft Finding Released July 22, 2015

http://www.lpi.usra.edu/sbag/findings/SBAG13_07102015.pdf



Regarding planetary defense deflection demonstrations such as ARM and AIDA:

The joint NASA-ESA Asteroid Impact and Deflection Assessment (AIDA) mission, which will measure the effect of a kinetic impactor on a moon of a binary asteroid, and NASA's test of the enhanced gravity tractor concept as part of its **proposed Asteroid Redirect Mission (ARM)**, which would utilize a boulder from the target asteroid to increase the mass of the gravity tractor, **would both help lower uncertainties of these two deflection techniques and give confidence about capabilities to move an asteroid in a controlled way.**

Both of these missions have significant science benefits and are representative of how we can build confidence in deflection technologies by merging the two interests.

Final Report Posted July 22, 2015

<http://iaaweb.org/iaa/Scientific%20Activity/pdcreportfinal.pdf>

Formulation Assessment and Support Team (FAST)



- Formulation Assessment and Support Team (FAST) will consist of NASA and non-NASA participants who will:
 - participate in requirement formulation efforts during the initial development phase of the Asteroid Redirect Robotic Mission (ARRM) in support of the ARRM Requirements Closure Technical Interchange Meeting (TIM) currently planned for mid-December of 2015
 - provide initial inputs for potential investigations and payloads related to the following four main areas:
 - **Science**
 - **Planetary Defense**
 - **Asteroidal Resources and In-Situ Resource Utilization (ISRU)**
 - **Capability/Technology Demonstration**
 - work in collaboration with ARM management and technical personnel at the participating field centers to provide input during the requirements definition phase of the ARRM, which includes spacecraft interfaces, requirements, and design considerations as they relate to the Asteroid Redirect Crewed Mission (ARCM).
 - provide input to NASA on potential secondary payloads and partnerships.

Formulation Assessment and Support Team (FAST)

Planned Structure and Milestones



- U.S. Membership
 - Approximately 12-15 unfunded participant members.
 - Composed of NASA and non-NASA participants plus Mission Investigator, Deputy Investigator, and Analysis and Integration Lead.
 - Final product will be in the form of a report to NASA
- Membership call is planned on or around July 7th (courtesy notification was issued on June 23rd via NSPIRES).
- Funded travel planned for two in-person team meetings (kick-off and final) with 2-3 virtual meetings in between.
 - Kick-off meeting planned for mid-September 2015
 - Final meeting planned for mid-November 2015
- The final report of the ARM FAST will be submitted to NASA around November 20, 2015. The final report is expected to be released publically and available for comment. After the report is finalized FAST will be disbanded.

ARM Investigation Team (IT)



- The purpose of the multidisciplinary Investigation Team (IT) is to assist with the definition and support of investigations in the following four main areas as they pertain to the robotic and crewed segment objectives:
 - **Science**
 - **Planetary Defense**
 - **Asteroidal Resources and In-Situ Resource Utilization (ISRU)**
 - **Capability/Technology Demonstration**
- The IT supports ARM program-level and project-level functions, provides technical expertise, and supports HQ interactions with the technical communities. Includes support of:
 - **Mission formulation (e.g., concept development for robotic and crew segments)**
 - **Mission design and vehicle development (e.g., asteroid landing/capture system)**
 - **Mission implementation (e.g., close proximity operations, crew sampling, etc.)**
- The IT will also provide input into extensibility, commercialization, and partnership activities in close coordination with other agency efforts.

Investigation Team Planned Structure and Milestones



- U.S. Membership
 - **NASA appointed Mission Investigator, Deputy Investigator, and Analysis and Integration Lead.**
 - **Selection of additional members**
 - **Nominally 50% NASA and 50% non-NASA membership**
 - **Team size and level-of-effort are TBD**
 - **Funds provided to cover participation and travel**
- International and Commercial Membership
 - **Invited guest members as mutually beneficial opportunities arise**
 - **All participation and travel expenses to be covered by their respective institutions**
- Planned membership call in January 2016 and team kick-off by mid-2016
- The initial term of membership will be nominally three years, but may be extended.

ARM External Opportunities



- **NASA continues to pursue commercial, academic, and international partnership opportunities**
 - **FAST for the remainder of this calendar year**
 - **Invited in June international expressions of interest in partnerships to inform ASM**
 - **Significant opportunities exist within baseline robotic mission capabilities and operations.**
 - **Ongoing discussions regarding consideration of commercial and potential international partnerships.**
 - **Accommodations (mass, power, volume, and data) for hosted and deployable payloads on the Asteroid Redirect Robotic Mission (ARRM) spacecraft are currently planned, with the potential for secondary payloads on the launch vehicle.**
- **Considerations continue for opportunities for partnerships during the Asteroid Redirect Crewed Mission (ARCM), including for extensibility.**



ARM Near Term Milestones

- Asteroid Redirect Robotic Mission (ARRM) Jun 22
Implementation Approach Agency discussion #1
- Formulation investigation team* courtesy letter released Jun 24
- Spacecraft bus Request for Information responses due Jun 29
- Small Bodies Assessment Group Meeting June 29
- ARRM Implementation Approach Agency discussion #2 Jul 6
- Spacecraft bus Request for Information Assessments Jul 15
- NewSpace Conference Jul 16-17
- ARRM ASM preparation face-to-face meeting Jul 20-23
- STMD Electric Propulsion Request for Proposal Release Jul 25
- **NASA Advisory Committee HEO Committee Meeting Jul 27-30**
- **Draft common visible/Infra-Red camera spec release Jul 30**
- **STMD 2nd thruster test unit fab and assembly complete Aug 3**
- **ARRM Acquisition Strategy Meeting Aug 4**
- **Requirements Closure Technical Interchange Meeting Dec 15 (TBR)**
- **Key Decision Point-B Feb 2016 (TBR)**

* Formulation Assessment and Support Team (Sept - Dec 2015)